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H4L LFNB LFNX

(56) Documents Cited
GB 2269963 A EP 0597525 A1 US 5226088 A

(58) Field of Search
UK CL (Edition N) H4L LFNA LFNB LFNX
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ON-LINE : WPI

(54) Noise-excising Communications Receiver

(57) A receiver extracts a wanted VLF signal from a wide signal band also containing unwanted signals and impulsive noise. Analyser 103 identifies the most powerful unwanted signals and sets mix frequencies for unwanted signal removal and noise excision stages 202, 203, 204. Each stage detects noise above a threshold l vel, set above the mean signal band power, excises the noise, patches the signal and removes the unwanted signal. The wanted signal is extracted by final stage 205. Unwanted signals are removed in decreasing order of power. The analyser may use a spectral analysis (FFT) technique on blocks of the received signal.

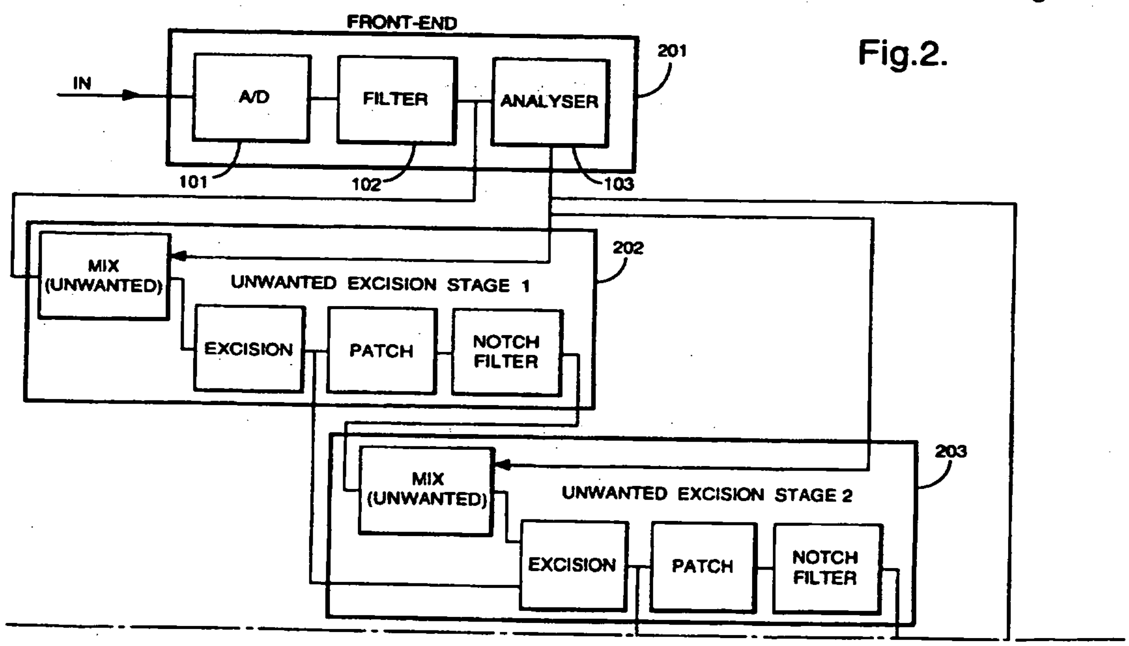


Fig.2.

GB 2 304 000 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig.1.

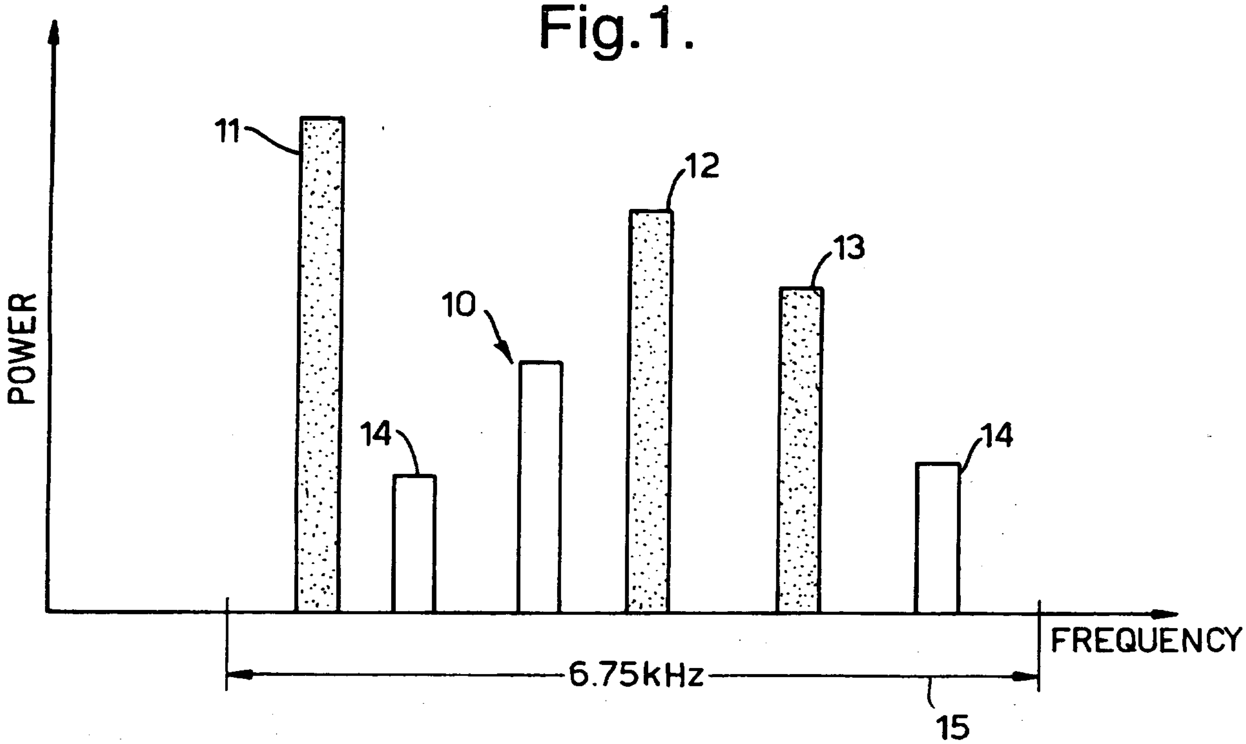

POWER
11
12
13
10
14
14
FREQUENCY
6.75kHz
15

Fig.5.

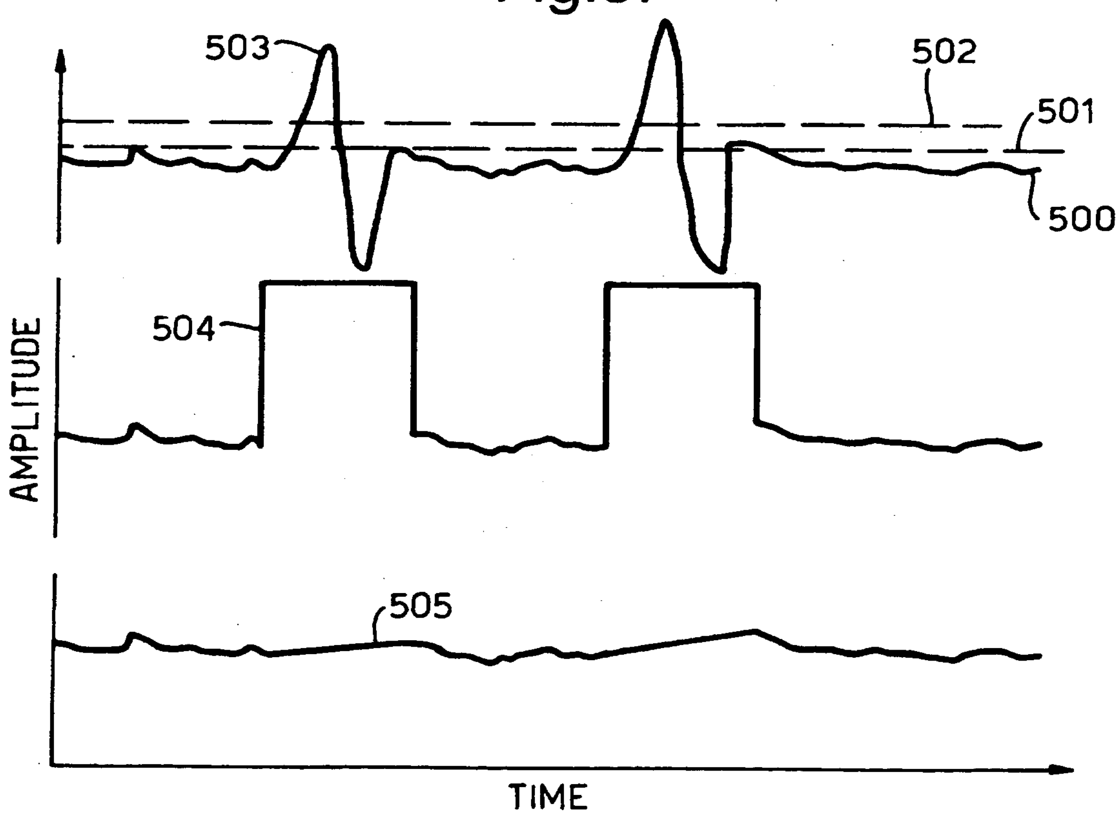

503
502
501
500
504
AMPLITUDE
505
TIME

Fig.2.

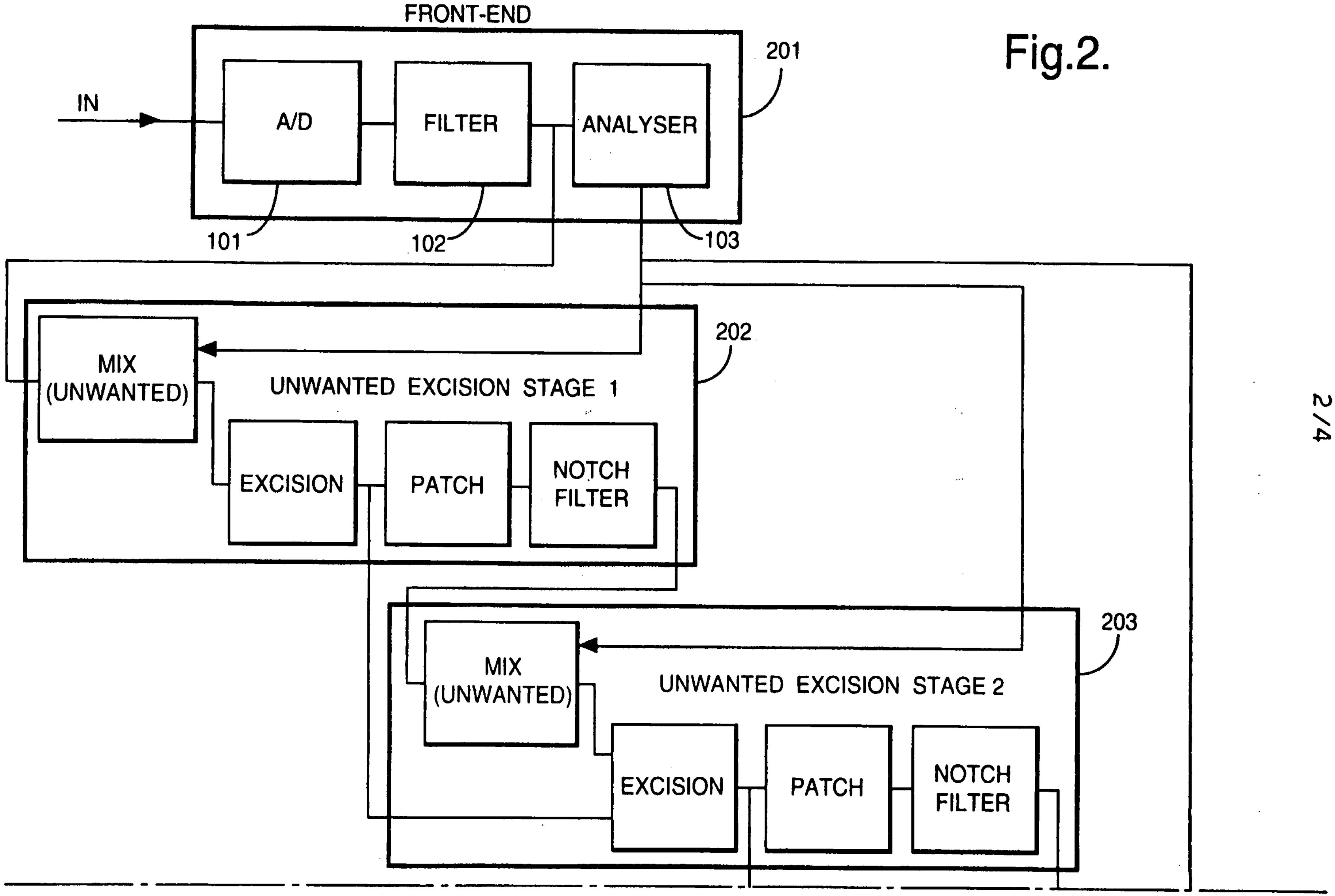

FRONT-END
IN
A/D
FILTER
ANALYSER
201
101
102
103
202
MIX (UNWANTED)
UNWANTED EXCISION STAGE 1
EXCISION
PATCH
NOTCH FILTER
203
MIX (UNWANTED)
UNWANTED EXCISION STAGE 2
EXCISION
PATCH
NOTCH FILTER

Fig.2 (Cont).

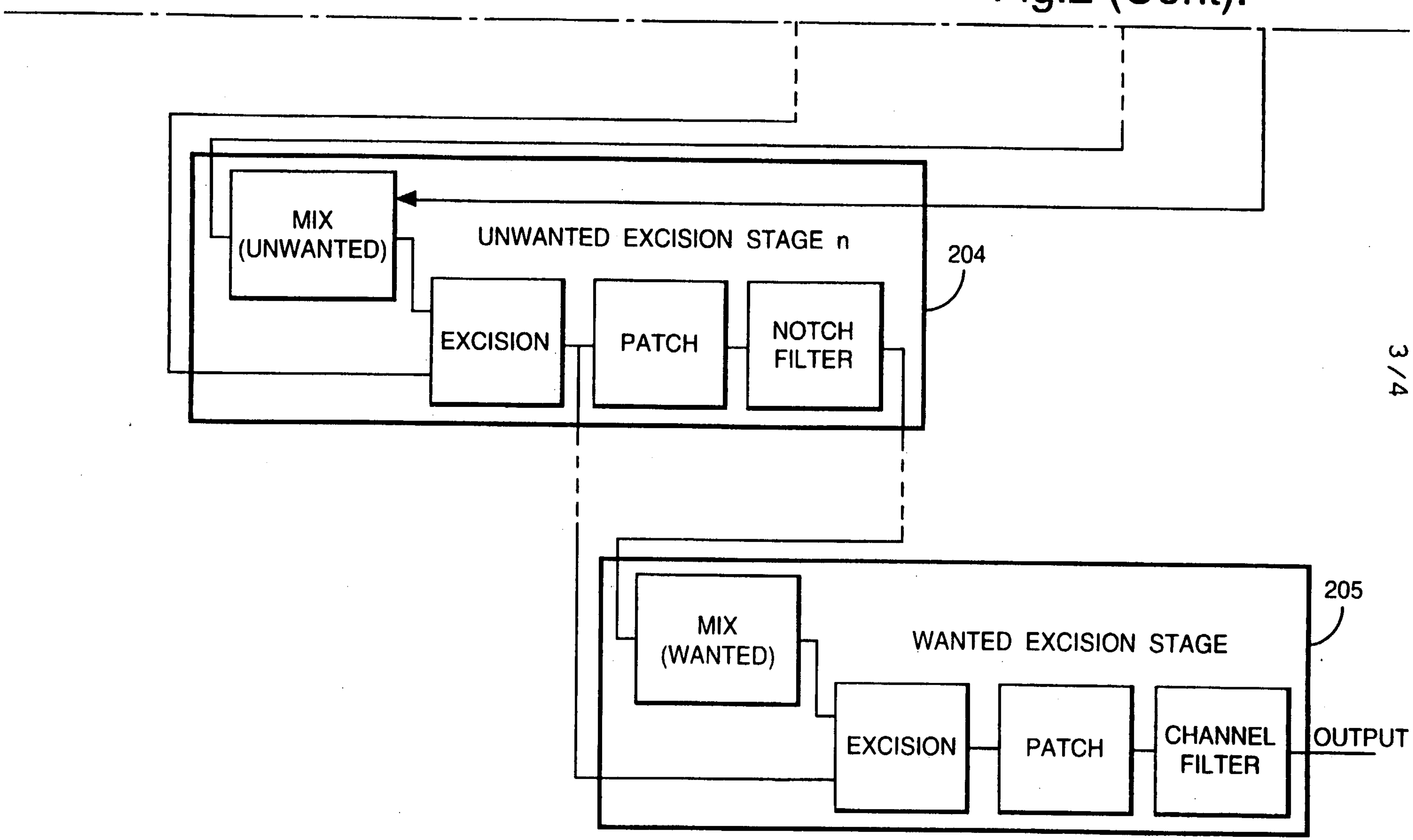

MIX
(UNWANTED)
UNWANTED EXCISION STAGE n
204
EXCISION
PATCH
NOTCH
FILTER
MIX
(WANTED)
WANTED EXCISION STAGE
205
EXCISION
PATCH
CHANNEL
FILTER
OUTPUT

Fig.3.

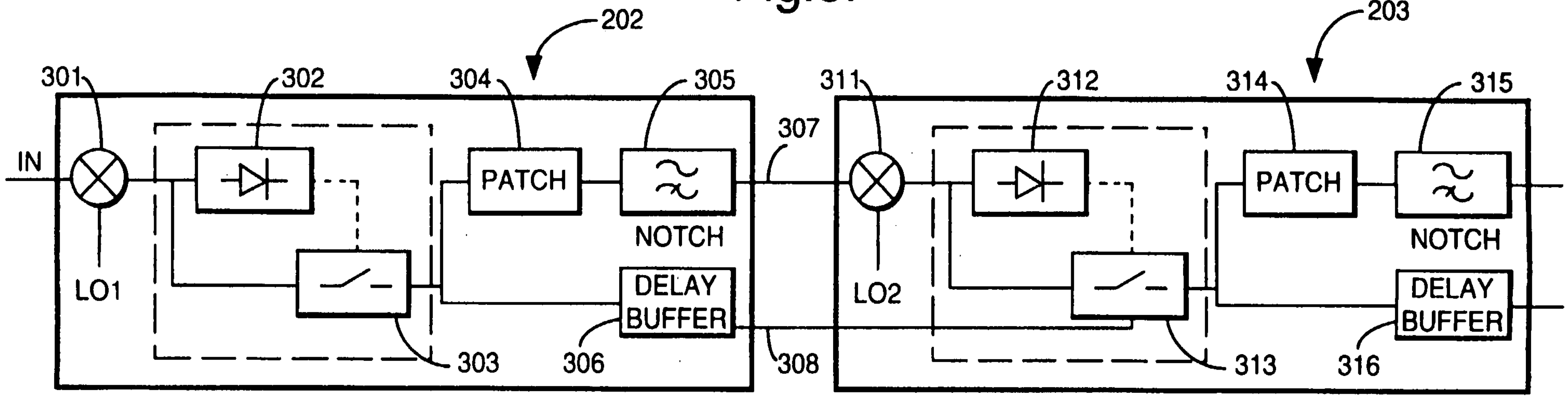
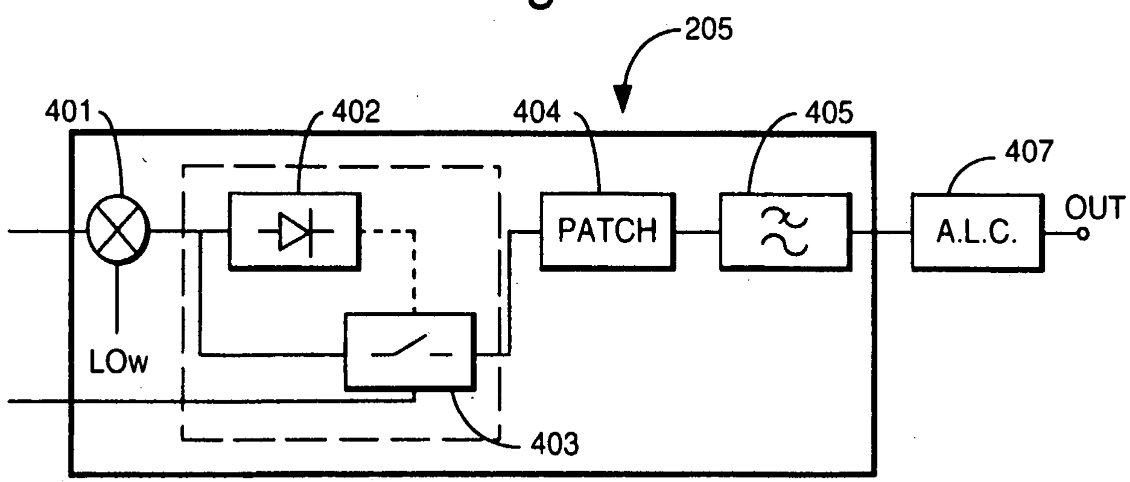

202
203
301
302
303
304
305
306
307
308
311
312
313
314
315
316
IN
LO1
LO2
PATCH
PATCH
NOTCH
NOTCH
DELAY BUFFER
DELAY BUFFER

Fig.4.


205
401
402
403
404
405
407
LOw
PATCH
A.L.C.
OUT

NOISE-EXCISING COMMUNICATIONS RECEIVER

This invention relates to a communications receiver for use in the VLF band.

The very low frequency (VLF) band allows communication over considerable distances, but suffers from interference from atmospheric noise such as that caused by lightning. Lightning around the world causes impulsive interfering signals which, due to their high power, can cause considerable corruption of communications signals.

Ideally a receiver would use a narrow-band filter at its front-end to extract a wanted signal and attenuate as much interference as possible. However, if a narrow-band filter is used it has the effect of spreading impulsive noise in time, thereby corrupting the wanted signal.

An alternative approach must be adopted. UK Patent Application GB 2,269,963A describes one such alternative arrangement for excising impulsive noise from a VLF signal. According to this specification, impulsive noise spikes are detected, removed, and replaced by a locally generated signal approximating the removed part of the signal before the wanted signal is extracted. This process may be repeated with lower detection thresholds to remove increasingly smaller noise spikes. This specification also teaches how a wanted signal may be extracted in the presence of a single interfering signal and impulsive noise. This is an ideallic situation which is rarely encountered in reality. Because of the wide filter used at the front end of the receiver, a number of strong interfering signals and impulsive noise are passed. These must be removed before the wanted signal can be extracted.

It is an object of the pres nt invention to provide a receiver which allows a wanted signal to b extracted from a band containing a plurality of unwanted signals and impulsive noise.

According to the present invention there is provided a method of extracting a wanted VLF signal from a signal band containing a plurality of unwanted signals and impulsive noise, comprising the steps of:

(i) setting a threshold level greater than the mean power across the signal band;

(ii) excising impulsive noise above the threshold level;

(iii) removing the most powerful unwanted signal within the signal band;

(iv) repeating steps (i)-(iii) for other unwanted signals in the signal band, in decreasing order of signal power, thereby successively reducing the level of impulsive noise and leaving the wanted signal.

The invention also provides a receiver for extracting a wanted VLF signal from a received signal band containing a plurality of unwanted signals and impulsive noise, comprising:

setting means for setting a threshold level greater than the mean power across the received signal band;

excision means for excising, from the received signal band, impulsive noise above the threshold level;

filtering means for removing the most powerful unwanted signal within the received signal band;

wherein the received signal band is routed through the setting means, excision means and filtering means for decreasingly less powerful unwanted signals to reduce the level of impulsive noise.

Preferably the method further comprises an initial step of identifying unwanted signals within the signal band.

The step of identifying unwanted signals preferably involves performing spectral analysis on the signal band over a period of time.

Ideally steps (i)-(iii) of the method are repeated for all unwanted signals which are more powerful than the wanted signal.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows a typical scenario in which the invention may be used;

Figure 2 is a block diagram of the excision process used in the receiver;

Figure 3 is a more detailed diagram of the first excision stages of Figure 2;

Figure 4 is a more detailed diagram of the final excision stage of Figure 2;

Figure 5 shows the noise-excising process in the time domain.

A receiver is required to operate across a range of frequencies e.g. 10-60 kHz. The wanted channel within this band may typically be of the order of 200 Hz wide. Ideally a reasonably narrow filter, centred on the wanted channel, would be used to extract that channel. However, the presence of high-level impulsive noise prevents the use of such a narrow filter. Therefore a relatively wide band filter is used at the receiver front-end. Typically this is a 6.75kHz filter. Figure 1 shows a typical plot of the band of signals which is passed by the front-end filter. With such a wide pass-band 15, it is reasonable to expect a number of unwanted signals 11, 12, 13, 14 to be present in addition to the wanted signal 10. These unwanted signals may be more powerful than the wanted signal.

Figure 2 shows the process to remove the unwanted signals 11, 12, 13, excise impulsive noise and to extract the wanted signal 10. This process removes unwanted signals in decreasing order of signal power, each stage removing an unwanted signal and reducing the impulsive noise to around the same level as that of the unwanted signal in that stage.

Front end 201 performs initial processing of the signal. An incoming VLF signal is passed through an analogue-to-digital converter 101 to enable all subsequent processing to be carried out in the digital domain, by software. By the processes of mixing, digital filtering and down-sampling, shown generally as filter 102, a sub-band of the received VLF signal band is selected. A typical 6.75kHz sub-band is shown. This sub-band is analysed 103 to identify unwanted signals within the pass-band.

A plurality of signal removal and noise excision stages 202, 203, 204 successively operate on the sub-band. A final stage 205 operates on the

remaining, wanted signal and further reduces impulsive nois . The plurality of stages may be achieved by using a dedicat d piece of apparatus for each stage, and connecting the apparatus together such that a signal is cascaded through each dedicated apparatus. Alternatively, a signal may be iteratively routed through a single piece of apparatus, with the apparatus being re-programmed to perform the functions of the next stage after each iteration.

The signal removal and noise excision stages will now be explained in more detail with reference to figures 3 and 4.

First stage 202 removes the most powerful of the unwanted signals identified by analyser 103. Mixer 301 mixes the input with a first local oscillator signal L01 such that the unwanted signal is moved to baseband. This baseband signal is fed to detector 302 and to a gate 303. Detector 302 operates the gate 303 to mark those portions of the signal which exceed a pre-determined threshold. The threshold is typically set 6-12dB above the average signal power across the total sub-band, to respond to impulsive noise. The precise threshold setting is chosen for optimum performance. The width of the marked portion of the signal can be extended by a variable number of samples each side of the point at which the threshold is crossed. The marked signal is fed to a patch 304 and filter 305, and also to subsequent stage 203 via a delay buffer 306.

Patch 304 replaces each marked section of the signal with a signal approximating that which would have been present before corruption by the impulse. The simplest form of patch is a linear join between the portions of the signal each side of the marked section. Other forms of patch include polynomial functions, such as cubic polynomials, based on the value and slope of the signal immediately each side of the marked section of the signal. The patched signal is then filtered by a high-pass filter to remove the unwanted signal. The high-pass filter may typically have a stop-bandwidth of 770Hz. This acts as a notch on the 6.75kHz sub-band to remove a narrow of band of signals around the frequency of the the unwanted signal.

The output of this first stage 202 is the original sub-band from the front-end minus impulsive noise above the level of the most powerful in-band unwanted signal and minus that unwanted signal. This is carried by line

307. A further output is a marked signal delayed by buffer 306 to arrive at second gate circuit 313 simultaneously with the signal carried by line 307.

Further unwanted signals are likely to remain. Further stages 203, 204 remove the unwanted signals in decreasing order of signal power and reduce the level of impulsive noise.

Second excision stage 203 operates in a similar manner to the first excision stage 202. Mixer 311 mixes input 307 with a second local oscillator signal L02 to shift the second unwanted signal to baseband. Gate 313 marks sections of the signal which exceed a second pre-determined threshold. The gate receives control signals from detector 312 and from the previous stage 202 via line 308. This second threshold is typically set at a level of some 6-12dB above the average signal power across the sub-band. This average signal power will be lower than when calculated in the previous stage because the most powerful unwanted signal has now been removed.

Patch 314 patches across the marked sections of the signal and high-pass filter 315 removes the unwanted signal. The output of this second excision stage is the original signal band minus the two most powerful unwanted signals (e.g. 11 and 12 shown in figure 1) and impulsive noise down to around the original level of the second unwanted signal just removed.

Further stages may be added in cascade, each operating in the same manner as those just described, with an appropriate local oscillator signal to tune the unwanted signal to baseband and a detector set to an appropriate threshold level.

The remaining signal band is fed to a final stage 205. This performs a final noise excision operation on the wanted signal before extraction.

Mixer 401 mixes the incoming signal with a local oscillator signal LO_W to shift the wanted signal to baseband. Ideally this should contain no unwanted signal components of a power greater than that of the wanted signal.

Detector 402 detects any parts of the signal which exceed a pre-d termin d threshold and instructs gate 403 to mark them. This final threshold is typically set 6-12dB higher than the average power of the r maining signals across the sub-band. A final patch operation 404 is perform d, which includes patching across previously marked portions. A narrow low pass channel filter extracts the wanted signal, with level correction by Automatic Level Control 407.

This low pass filter has a bandwidth sufficient to extract the wanted signal from nearby interferers. This may be a bandwidth of 200 Hz. Subsequently the wanted signal is demodulated and further processed.

Ideally the unwanted signal removal and noise excision process is repeated to remove all unwanted signals of a power greater than the wanted signal.

Figure 5 illustrates the noise excision and patching process in the time domain. Signal 500 represents signal amplitude at the input to one of the excision stages 202, 203, 205 of Figure 2. This signal contains noise impulses 503 which must be removed. A detection threshold 502 is set at a level higher than that of the average signal power level 501. By setting a signal power threshold, both positive and negative noise spikes are detected. When the signal level crosses the detection threshold, as with impulse 503, the signal is marked 504. Marking is conveniently achieved by setting the signal value to maximum, a value which can be readily detected at the subsequent patching step. The signal is usually marked for a period which extends, by a variable time, each side of the period for which the signal exceeds the detection threshold. Patching the marked section of the signal results in section 505 replacing impulse 503.

Referring again to Figure 2, the incoming signal is analysed to determine the frequencies of the main unwanted signals. This function is performed by analyser block 103 of the front-end. The analyser samples data (representing the incoming signal band), performs Fast Fourier Transforms (FFTs) on the data, accumulates the results over a period of time and from these determines the largest unwanted in-band signals. The frequencies of the largest unwanted signals are used to calculate the values of the local oscillators L01, L02.. required in stages 202, 203, 204. Values of the local oscillators can be changed in software.

To accurately determine frequencies of the unwant d signals, FFT analysis must be performed on those portions of the signal which are free of impulsive noise. This is because high-level impulsive noise masks the unwanted signal frequencies. In general, the shorter the time window during which data samples are collected, the greater the probability that the signal during that period is free of impulsive noise. However, to perform a FFT of suitable resolution to discern unwanted signal frequencies to within 50-100Hz requires a 10-20ms window of data. A solution is based on using a number of short blocks of data. Each block of time samples is analysed to determine whether it contains impulses. This is achieved by:

(i) calculating the mean sample power across the block;

(ii) determining the maximum sample power within the block

and performing the calculation:

Is *maximum power* > *k* x *mean power*

where *k* typically has a value of 5.

If this is true then the block is considered to contain impulses and is discarded. A FFT is performed on each of the remaining blocks, and these are collated over a fixed time period to determine the unwanted signal frequencies. Standard windowing techniques are used on the data samples prior to performing a FFT.

CLAIMS

1. A method of extracting a wanted VLF signal from a signal band containing a plurality of unwanted signals and impulsive noise, comprising the steps of:

(i) setting a threshold level greater than the mean power across the signal band;

(ii) excising impulsive noise above the threshold level;

(iii) removing the most powerful unwanted signal within the signal band;

(iv) repeating steps (i)-(iii) for other unwanted signals in the signal band, in decreasing order of signal power, thereby successively reducing the level of impulsive noise and leaving the wanted signal.

2. A method as claimed in claim 1 further comprising an initial step of identifying unwanted signals within the signal band.

3. A method as claimed in claim 2 wherein spectral analysis is performed on the signal band over a period of time to identify the unwanted signals.

4. A method as claimed in claim 3 wherein spectral analysis is performed on blocks of samples of the signal band which are determined to be free of impulsive noise.

5. A method as claimed in any preceding claim wherein steps (i)-(iii) are repeated for any unwanted signals which are more powerful than the wanted signal.

6. A receiver for extracting a wanted VLF signal from a received signal band containing a plurality of unwanted signals and impulsive noise, comprising:

setting means for setting a threshold level greater than the mean power across the received signal band;

excision means for excising, from the received signal band, impulsive noise above the threshold level;

filtering means for removing the most powerful unwanted signal within the received signal band;

wherein the received signal band is routed through the setting means, excision means and filtering means for decreasingly less powerful unwanted signals to reduce the level of impulsive noise.

7. A receiver as claimed in claim 6 wherein the received signal band is iteratively routed through the setting means, excision means and filtering means for decreasingly less powerful unwanted signals to reduce the level of impulsive noise.

8. A receiver as claimed in claim 7 further comprising an analyser to identify unwanted signals within the received signal band.

9. A receiver as claimed in claim 8 wherein the analyser performs spectral analysis on the received signal band over a period of time to identify the unwanted signals.

10. A receiver as claimed in claim 9 wherein the analyser performs spectral analysis on blocks of samples of the signal band which are determined to be free of impulsive noise.

11. A receiver as claimed in any one of claims 6 to 10 wherein the received signal band is selected by a filter which is of such a bandwidth so as not to substantially spread the impulsive noise.

12. A receiver substantially as described herein with reference to and as illustrated in the accompanying drawings.

13. A method of extracting a wanted VLF signal substantially as described herein with reference to and as illustrated in the accompanying drawings.

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Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report)

Application number
GB 9515963.8

Relevant Technical Fields

(i) UK Cl (Ed.N) H4L - (LFNB, LFNA, LFNX)

(ii) Int Cl (Ed.6) H04B - (1/10)

Search Examiner
P S DERRY

Date of completion of Search
19 OCTOBER 1995

Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE: WPI

Documents considered relevant following a search in respect of Claims :-
1-11

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
A	GB 2269963 A	(NORTHERN TELECOM) see whole document	
A	EP 0597525 A1	(PHILLIPS) see whole document, especially column 4	
A	US 5226088	(WINTERNER) see especially Figure 1	

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).